Comparing Upper Arm and Back Postural Exposures between Apple Harvesting with Ladders and Mobile Platform

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In the US tree fruit industry, in attempt to improve the efficiency of orchard workers; harvest-assisting mobile platforms have been introduced. However, the effect these mobile platforms have on physical exposures, i.e. non-neutral work postures, has not been evaluated. The purposes of this study were to compare ergonomic risk factors between a new apple harvesting method using mobile platforms and the traditional method using ladders. Twenty-four workers participated in this study and were equally divided into three groups, harvesting apples from ladders (n = 8), mobile platforms (n = 8) and the ground (n = 8). Upper arm and back inclinations were continuously monitored and calculated over the whole work period, excluding breaks. Upper arm posture was characterized in terms of the percent of time when upper arm flexion and abduction exceeded 30, 40, 50, 60, 70 80 and 90 degrees. Back inclination was characterized as the percent time forward bending exceeded 10, 20 and 30 degrees. The results showed that the workers on the mobile platform typically had lower postural exposures than the ground and the ladder workers, respectively.

INTRODUCTION

In North America, labor costs and a shortage of labor have been critical issues facing the tree fruit industry. Manual harvesting is the task performed most frequently in apple orchards (McCurdy et al., 2003). Several commercialized tree fruit orchards in the United States have adopted new technology, a harvest-assisted mobile platform, in attempt to make harvesting more economical. With such technology, workers can pick fruit from trees while standing on a semi-autonomously moving platform without having to climb up and down ladders.

The change in work methods from implementing the harvest-assist mobile platforms may change the exposures to the risk factors associated with work-related musculoskeletal disorders (WMSDs); in particular, physical exposures including prolonged non-neutral postures in the back and upper extremities. In a previous study of apple harvesting using ladders, workers were exposed to physical stress including reaching to pick apples for 62.9% of the work time and carrying an apple bag for 78.5% of the time (Fulmer et al., 2002). Even though implementing the mobile platform has potential to improve harvesting efficiency, there has not been a study investigating how mobile platforms may affect the physical exposures an orchard worker is subjected to.

Physical exposures can be assessed by visual observation such as RULA (McAtamney & Nigel Corlett, 1993) and REBA (Hignett & McAtamney, 2000). Although observation-based methods are systematic and user-friendly, they may not always be accurate. A previous laboratory study found that experienced ergonomists misclassified shoulder angle categories as comparing to results from direct measurement using optical sensors (Lowe, 2004). However, these sophisticated direct measurement motion capture techniques are not well suited for studying agricultural work in actual field settings.

To overcome the some of the challenges of using direct measurement techniques in actual field settings, this study used accelerometers for measuring and characterizing upper arm and back postures during agricultural work. Therefore, the purpose of this study was to determine whether there were differences in upper arm and back postural exposures between the traditional method of harvesting apples with a ladder and the new method using mobile platforms.

METHODS

Study Design

Subjects. Twenty-four workers participated in this study. All participants were males of Hispanic origin, native Spanish speakers and having at least one season of apple harvesting experience. The participants were equally divided into three groups (ladder, platform and ground). Not all the participants were experienced with ladder use; therefore, only those participants who had experience using ladders participated in the ladder group. The rest of the participants were randomly assigned to either platform or ground group. All the participants were paid by the amount of apples they picked. All study procedures were approved by the Human Subjects Division at the University of Washington. Table 1 presents the descriptive statistics of the participant's anthropometric and demographic characteristics. The p-values represent the statistical significance of the differences across the groups.

Harvesting task. All the workers were assigned to pick apples at a trellised orchard where all the trees were 7.5 years old. As can be seen in Figure 1, a trellised orchard is where the trees are trained to grow vertically along a central trellis; this orchard configuration is becoming standard in Washington State. The orchard workers were "color picking" which means they were only picking apples with a desired color and size.

The conventional way of harvesting apples involves ladders where the worker climbs up the ladder with front-mounted bag strapped around the shoulders. Typically the workers will climb the ladder and start harvesting apples from the highest point of the tree and fill their bag with apples as they move their way down the ladder. Once their apple bag is full (typically 20 kg) the workers walks to an apple bin, bends over and sets the apple bag in the bin, opens the bottom of their apple bag, and gently disperses the apples into the bin. The ground workers' work is similar except they pick the apples on the lowest part of the tree from the ground.

A new method of picking apples in Washington State involves the use of mobile platforms (Figure 1). These mobile platforms (*Bandit Xpress, Automated Ag Systems, Moses Lake, WA, USA*) have two platforms which are height adjustable: typically one platform is set to a lower level (to harvest from the lower portions of the tree) and the other platform is adjusted to a higher level (for harvesting from the higher portions of the tree). Like the other workers, a front-mounted apple bag was used to hold the apples, and then when full, the apples are deposited into a wood bin in the center of the platform.

Table 1 – Workers' anthropometric and demography

	Mean (SD)			
	Ground N = 8	Ladder N = 8	Platform N = 8	p-value
Age (years)	23.9 (1.4)	32.5 (3.0)	28.3 (3.0)	0.09
Weight (kg)	83.9 (4.9)	71.4 (4.5)	74.7 (2.4)	0.11
Height (cm)	177 (3.3)	170 (2.4)	171 (2.4)	0.16
Arm length (cm)	65.6 (1.6)	63.6 (1.0)	66.1 (1.3)	0.36
Upper arm length (cm)	37.1 (1.0)	35.4 (0.4)	35.7 (0.6)	0.26
Forearm length (cm)	35.4 (1.1)	34.7 (0.5)	35.4 (0.9)	0.80
Work experience (seasons)	1.4 (0.3)	2.0 (0.3)	1.3 (0.2)	0.08

Figure 1 – Harvest-assisting mobile platform

Data Collection

Equipment. To record upper arm and back postures, small devices with integrated tri-axial accelerometers *(G-Links; MicroStrain® Sensing Systems; Williston, VT*) were attached on the upper portions of the participants' left and right arms and their torso (Figure 2). The devices were battery powered, had 2 MB of built-in memory and recorded the continuous posture data at a frequency of 5 Hz. Each participant was measured for the entire work day of 8 hours.

Figure 2 – Measuring device attached to a participant

Signal Processing. At the beginning of the data collection, with the subject standing upright with their arms relaxed at their sides, reference postures were collected to determine the offsets associated with how the devices were attached to the body. In the graphical program, these offsets were subtracted. Then to eliminate noise, the raw data were then filtered using a dual-pass 1-Hz low-pass Butterworth filter. The offset and filtered data was used for characterizing the upper arm and back postures. The data were processed using an interactive graphical software program (LabVIEW 2014; National Instruments; Austin; Texas, USA).

Characterizing Postural Exposure. This study defined upper arm posture in terms of flexion (arm lifting forward in sagittal plane) and abduction (arm lifting sideways in coronal plane). Upper arm angles of flexion (θ_{ArmFL}) and abduction (θ_{ArmAB}) were calculated using equation (1) and (2), respectively, where x, y and z are the accelerations in frontal, sagittal and longitudinal axes, respectively. In addition, back forward bending angle (θ_{Back}) was calculated using equation (3).

$$\theta_{ArmFL} = \tan^{-1}\left(\frac{x}{z}\right) \qquad \text{eq. 1}$$

$$\theta_{ArmAB} = \tan^{-1}\left(\frac{y}{z}\right) \qquad \text{eq. 2}$$

$$\theta_{Back} = \tan^{-1}\left(\frac{x}{z}\right) \qquad \text{eq. 3}$$

In this study, the upper arm postural exposures were characterized in terms of the percentages of time when the upper arm angles of flexion and abduction exceeded 30°, 40°, 50°, 60°, 70°, 80° and 90°. When the upper arm angles exceed 90°, the arms were above shoulder level. Additionally, back postural exposures were characterized as the percentages of time when back forward bending was greater than 10°, 20° and 30°.

Statistical Analysis

Dependent and independent variables. The dependent variables of this study were the postural exposures in the upper arm and back, which were characterized as the percentage of work time in non-neutral postures. The independent variables were the harvesting method based on the equipment and the nature of work: (1) ladder, (2) platform and (3) ground and the time in the day (morning work period and afternoon work period).

The effects of the harvesting method and work period on the upper arm and back posture were determined using ANOVA methods with type I error of 0.05. If the work period did not have a significant effect on the independent variables, the parameters in two work periods were pooled together for the subsequent ANOVA analyses. JMP Statistical Discovery Software (version 11.2; SAS Institute; Cary; South Carolina, USA) was used to perform the statistical analysis.

RESULTS

The postural exposures in terms of the average angles of upper arm flexion, upper arm abduction and back bending were not found to differ between the two work periods (p-values > 0.05).

The postural exposures at the left and right upper arms were quite different, particularly with respect to upper arm flexion so postural data from left and right arm were analyzed separately (Table 2). As shown in Figure 3, the platform group generally experienced the least exposure to non-neutral upper arm postures (upper arm postures categories of 60° or greater) as compared to the ground and ladder groups.

For the upper arms, flexion in the left arm was lowest in the platform group and the ladder group had the largest variation in left arm flexion. In the right upper arm, on the other hand, there was no flexion differences except at the higher angle thresholds (80° and 90°), which were at or above shoulder level.

For upper arm abduction, the ladder group was exposed to slightly less left arm abduction below 30°, but significantly more abduction when considering the more extreme angle thresholds (≥70°). Right arm abduction was not significantly different across the three groups for angle thresholds below 60°. In contrast, at larger thresholds (≥70°), the platform group had significantly lower percentage of time at the more extreme angles when compared to the two other groups.

Similarly, as shown in Figure 4, there were significant differences in the exposure to forward leaning postures with the ground workers spending the greatest amount of time in forward leaning postures and the platform workers spending the least amount of time in the most extreme forward leaning postures. This was due to the fact that the participants in the ground group still had to pick apples from the lower levels of the tree, the same as the ladder group, but with greater frequency since the ladder group had more diverse tasks.

Table 2 – Postural exposures across work methods

	Mean (SE)			
Harvest Method	Ground N = 8	Ladder N = 8	Platform N = 8	p-value
Left arm flexion	19.2 (1.7)	12.4 (7.2)	5.9 (3.0)	0.06
Right arm flexion	22.7 (2.5)	21.1 (3.6)	18.8 (5.3)	0.80
Left arm abduction	15.7 (2.4)	10.5 (2.6)	15.3 (2.9)	0.37
Right arm abduction	13.0 (5.4)	17.2 (3.6)	11.2 (3.9)	0.59
Back inclination	10.4 (2.1)	-1.2 (3.7)	-0.6 (2.0)	0.23

DISCUSSION

This study presented an objective method for measuring work postures using inclinometers. Non-neutral postures of upper arms and back could be assessed using different thresholds of upper arm and back inclination. By analyzing the time spent above various angle thresholds, differences were identified across the various harvesting methods, especially in the upper arm. Mobile platform use reduced the exposures to overhead work but it did not substantially change the percentage of time the upper arms were used at the lower levels of arm elevation. For back postures, it could be concluded that the ground workers were exposed to greater back inclination but the differences between the ladder and platform workers were not significant.

Upper arm results were somewhat different from a previous study among the apple orchard workers in New York State (Earle-Richardson et al. 2005). In the previous study, different apple bucket design were evaluated while harvesting apples from ladders and the researchers sampled and timed the various work postures of the workers. Approximately 40% of work time both upper arms were in a neutral region (< 60°), about 30% of the time one upper arm was above 60° and about 30% of the time two upper arms were above 60°. The percentages of time in non-neutral upper arm postures assessed through this visual observation were much greater than our direct measurements obtained from the devices. Our measurement indicated that arm flexion or abduction over 60° was occurred less than 10% of the time which was much less the 30% estimate by Earle-Richardson et al. (2005). In other words, upper arm angles were less than 60° for more than 90% of the time in our study. This suggests the 60° threshold for defining non-neutral upper arm position may not be appropriate and smaller angles, such as the time the arms are above 30° should also be considered.

When the back postures in the ladder workers were compared to the New York study, the postural exposures were quite similar. In the study by Earle-Richardson et al. (2005), back postures were neutral (< 20°) for 63% of the time, inclined more than 20° for 23% of the time and inclined more than 45° for only about 4% of the time.

This study has a limitation in that it presented the postural exposures in terms of the proportion of time working above various angle thresholds but did not presented how fast or the number of repetitions or movements in the upper arm or the back, which are also risk factors which can contribute to

WMSDs. Since repetition can be computed from the acceleration data, these results can be tabulated. The workers were also videotaped for short periods of time and productivity and repetition data was evaluated using the videos. The methods and results were presented in Thamsuwan et al. 2015.

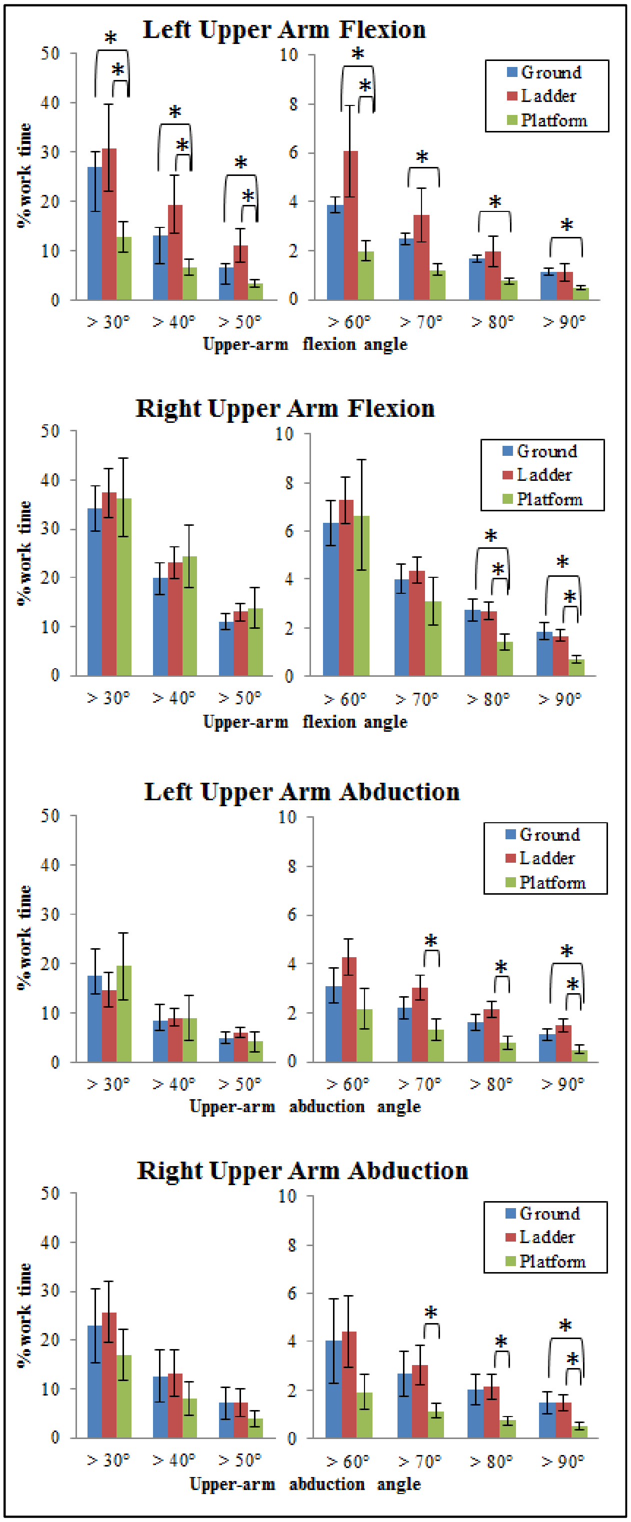

Figure 3 – Upper arm flexion and abduction

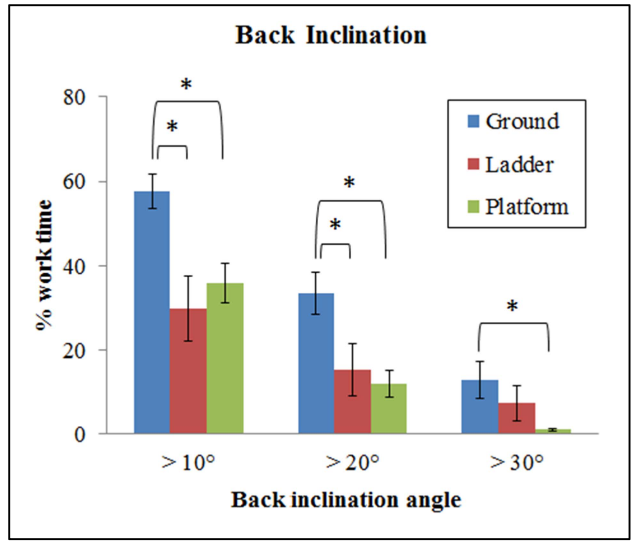

Figure 4 – Back inclination

Finally, even though this study was well-controlled, some caution may be merited with respect to generalizability. The study was conducted in a trellised orchard, which is a standard type of orchard in Washington State but may not be typical of orchards in other parts of the world. In this study, trees were grown as tree walls with a certain height in a trellised orchard. However, in other orchards, trees are generally taller and the growth of the branches is not constrained and the trees are typically wider and cover a greater area. Thus, harvesting work at these orchards where the tree growth is not constrained or controlled may expose workers to more non-neutral postures than in the trellised orchard in this study. Moreover, the type of apple harvested and the picking method (e.g. apple variety, clipping or not clipping stems, color picking, strip picking, 1st color pick, 2nd color pick, etc.) should also be taken in to consideration. In addition, the posture as well as the rate of movement might be related to work efficiency and/or harvesting productivity, which may depend on motivation such as a piece-rate pay scheme and a minimum requirement of amount picked. In other orchards, workers may get paid hourly instead of the piece-rate. All things considered, this study permitted a very fair and controlled comparison of the harvesting methods (the newly-developed mobile platform and the traditional use of the ladders) but caution may be merited when comparing to other apple harvesting studies.

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